KATHOLIEKE UNIVERSITEIT
LEUVEN

Repeatability and reproducibility of specular glossmeters in theory and practice

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Outline

- Introduction
- Test procedure
- Test results
- Theoretical consideration
- Conclusions

Introduction

- WP 2: GLOSS
  - Gloss artefacts (CNAM)
  - Determination of
    - BRDF (inside and outside of spec. peak) (CNAM & KUL)
    - specular gloss / haze / DOI (KUL & CMI)
  - Extend characterization to an investigation of the agreement between specular gloss meters (KUL)

- Scope
  - Determination of the agreement between specular glossmeter readings
  - ASTM D523-14 / ISO 2813:2014

DUTs

- Distributors / Manufacturers of specular glossmeters contacted

Manufacturer	BYKGardner		Rhopoint/Minolta		Zehntner	
Instrument type	micro-TRI-gloss	Micro-TRI-gloss S	IQ Flex 20	IQ Trigloss	ZGM 1110	ZGM 1120
Measurement geometry	20°/60°/85°	20°/60°/85°	20°	20°/60°/85°	20°/60°/85°	20°/60°/85°
Repeatability	± 0.2 GU	± 0.2 GU (± 0.1 GU)*	± 0.2 GU	± 0.2 GU	± 0.1 GU	± 0.1 GU
Reproducibility	± 0.5 GU	± 0.5 GU (± 0.2 GU)*	± 0.5 GU	± 0.5 GU	± 0.5 GU	± 0.5 GU
Calibration traceability	BAM	BAM	BAM	BAM	BAM	BAM

* Repeatability and reproducibility in the range of 0 – 10 GU (60° geometry).

Test specimen

- Gloss scale – 40 samples
  - Lightness (white, grey, black)
  - Refractive index (1.47 vs. 1.53)
  - Roughness (3 levels)

- 25 samples selected
  - Between 2 GU and 110 GU (60° geometry)

Measurement procedure

- Series of 5 measurements in each measurement geometry (except Rhopoint IQ Flex 20)

- Uniformity / Directionality
  - Average – relative standard deviation
  - 2 out of the 5 measurements with glossmeters turned over 90°

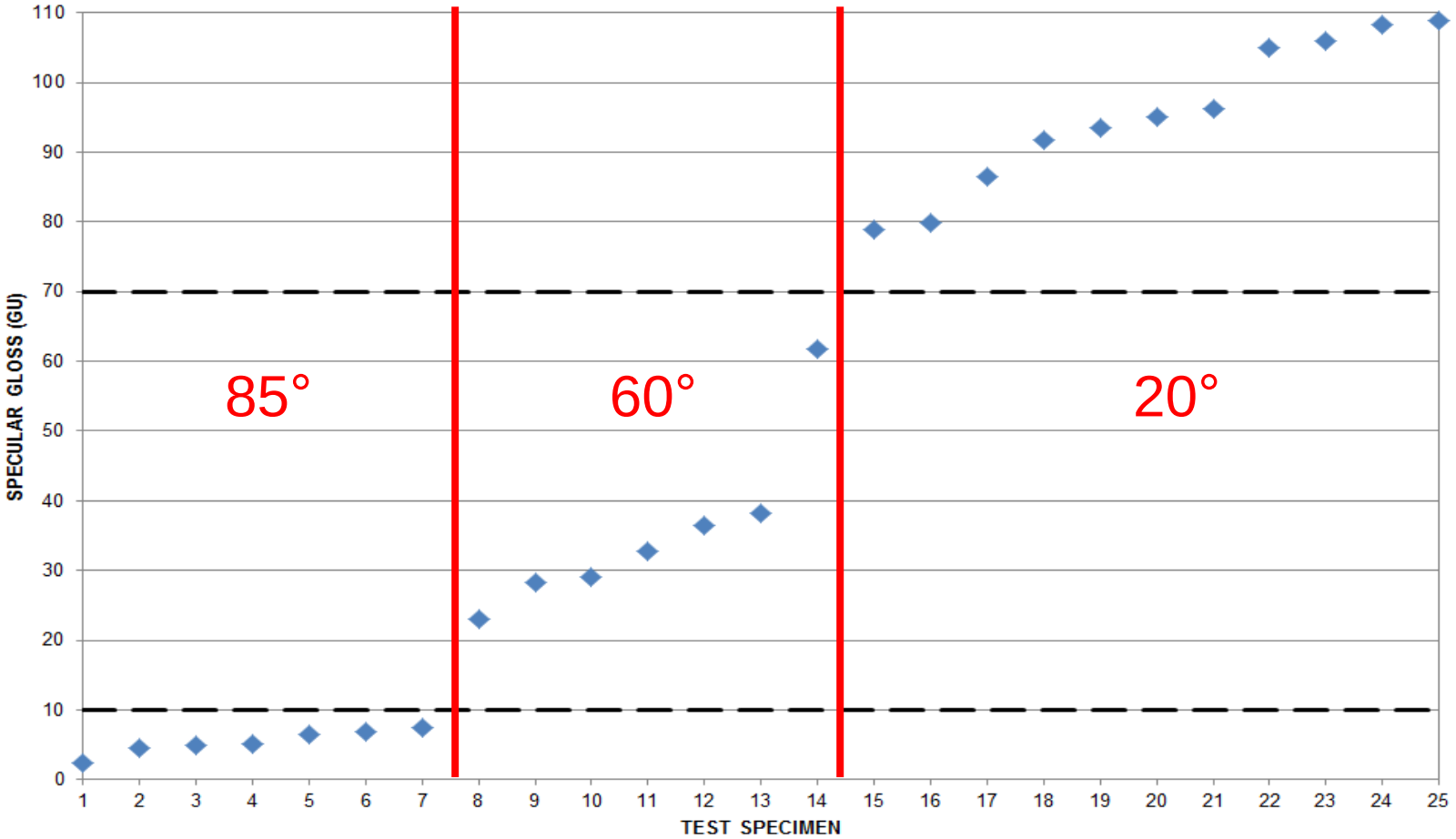
Measurement procedure

- Repeatability
  - agreement between 2 results from single determinations obtained on the same specimen with the same instrument
  - Checked from (max – min) of 5 readings

- Reproducibility
  - agreement between 2 results, each being the average of 5 consecutive readings with an instrument, obtained on the same specimen by use of different instrumentation
  - $(GU_{Avg,Max} – GU_{Avg,Min})$
  - $(GU_{Avg,Instr\_X} – GU_{Avg,Instr\_Y})$

- Checked in recommended measurement geometry

Measurement results – 60° geometry



Measurement results

- On the exception of 4 samples (samples 8 – 11 / low/mid-gloss range), samples show good uniformity

- Repeatability generally inferior to
  - Specified values manufacturers
  - Specified recommendations of standardization bodies (for each instrument, for at least 20 out of the 25 samples)

Measurement results - repeatability

Sample	Repeatability (GU)	Sample	Repeatability (GU)	Sample	Repeatability (GU)
1	0.7	10	12.6	19	1.0
2	0.4	11	17.1	20	4.1
3	3.0	12	3.1	21	3.6
4	3.3	13	4.4	22	2.2
5	4.1	14	7.0	23	3.2
6	2.7	15	8.3	24	3.8
7	6.4	16	5.7	25	4.4
8	11.3	17	0.9		
9	11.2	18	2.4		

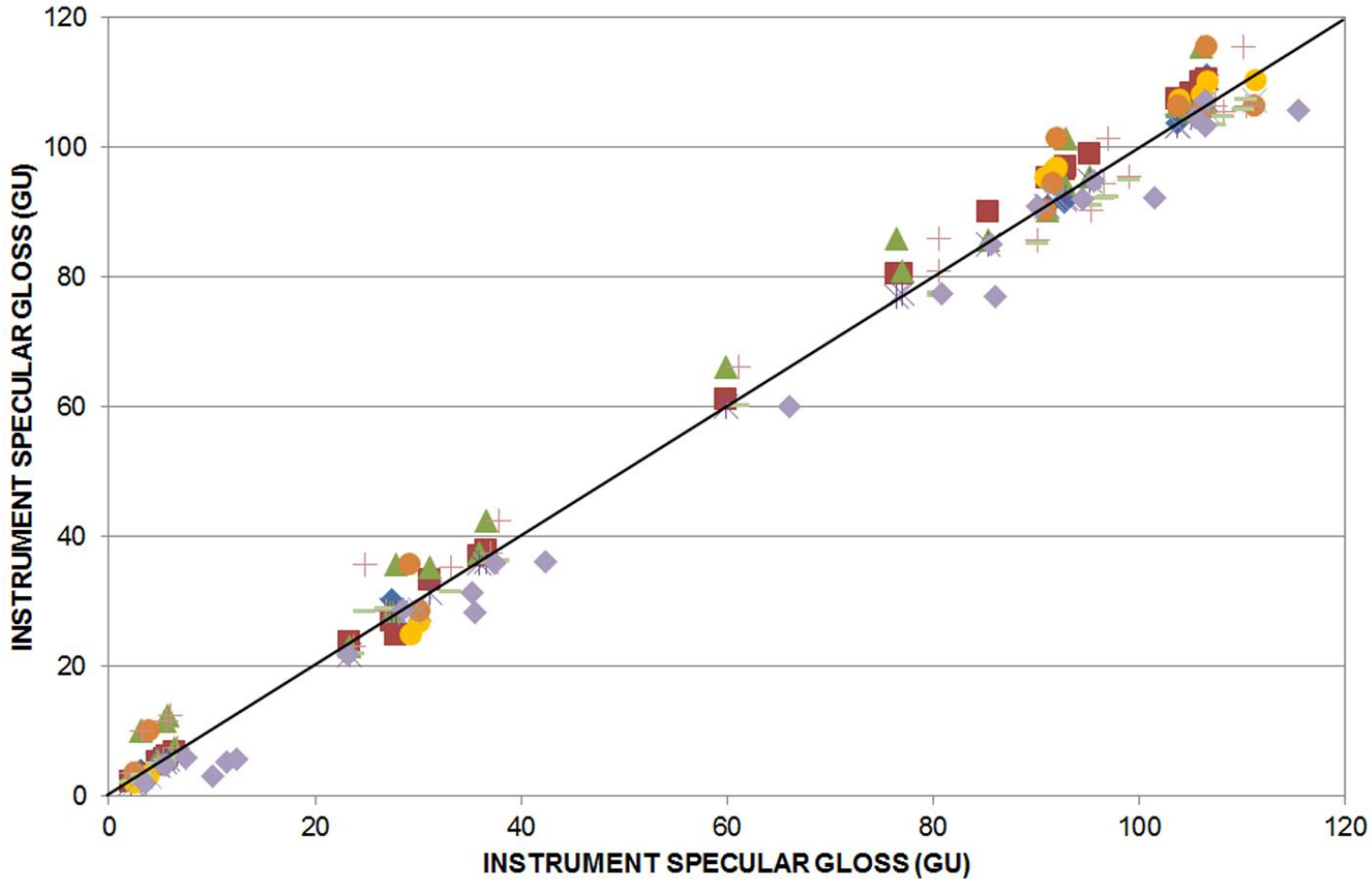
Measurement results - reproducibility

Sample	Reproducibility (GU)	Sample	Reproducibility (GU)	Sample	Reproducibility (GU)
1	0.8	10	10.7	19	13.9
2	0.9	11	4.1	20	14.3
3	1.9	12	1.6	21	9.2
4	1.4	13	6.2	22	7.7
5	1.8	14	6.1	23	7.2
6	1.8	15	3.2	24	8.5
7	2.7	16	8.9	25	9.1
8	2.2	17	9.9		
9	3.3	18	10.5		

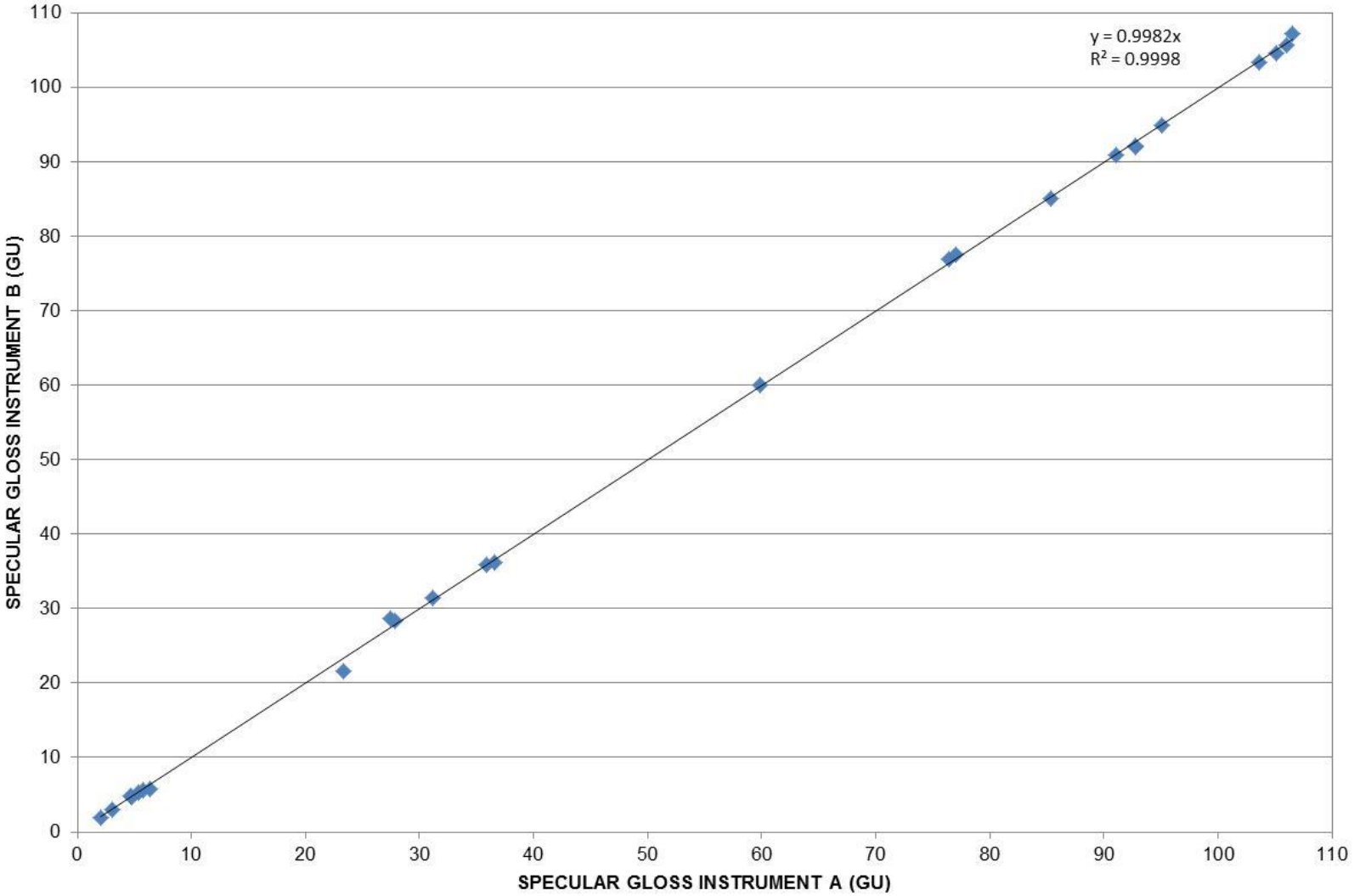
Measurement results - reproducibility

- Reproducibilty
  - All instruments
    - 20° geometry - worst, 60° geometry - better, 85° geometry - best
  - Each 2 instruments
    - Reproducibility better
    - 3 (15) combinations of 2 glossmeters: all differences below threshold
    - Best agreement for 2 glossmeters from same manufacturer
      - Not for the two other manufacturers: differences again above threshold!

Measurement results - Correlation



Measurement results - Correlation

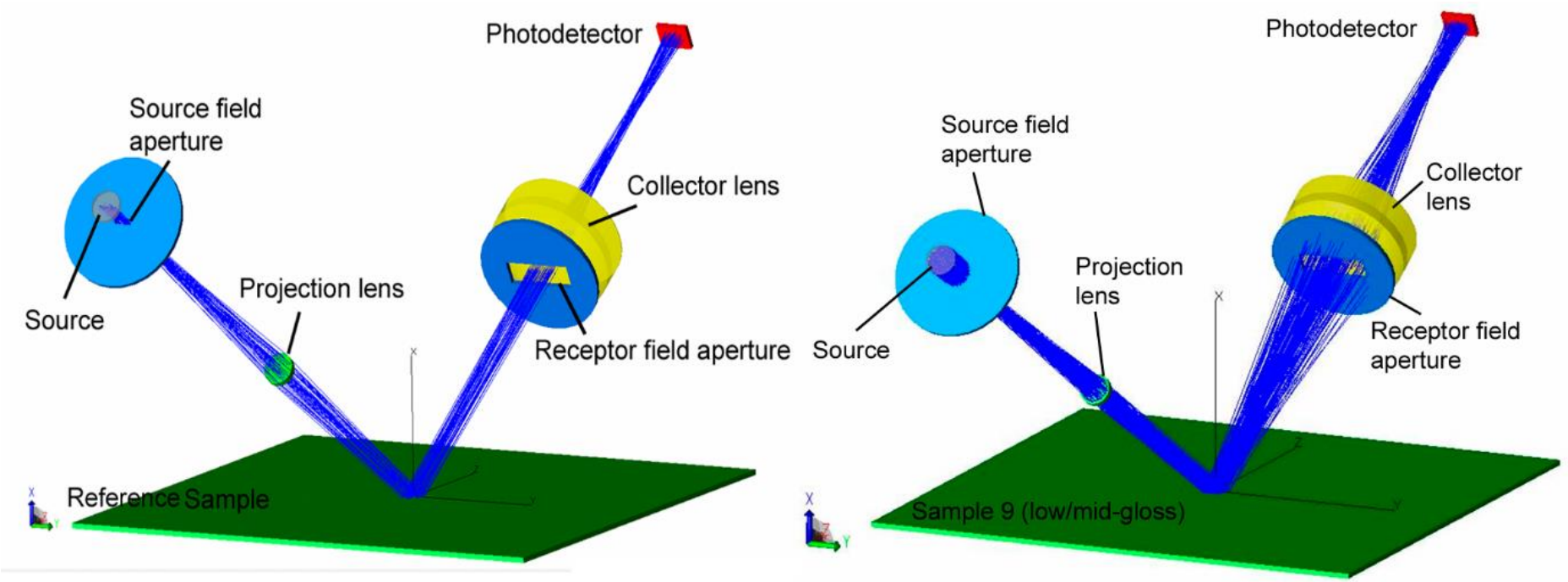


Measurement results - Correlation

Sample	Reproducibility (GU)		Sample	Reproducibility (GU)		Sample	Reproducibility (GU)	
	Before	After		Before	After		Before	After
1	0.0	0.3	10	9.9	3.2	19	0.7	2.1
2	0.3	0.0	11	8.7	3.3	20	1.7	1.2
3	0.4	1.4	12	8.9	3.0	21	10.7	4.8
4	0.0	0.4	13	10.3	2.5	22	2.1	1.2
5	1.2	0.7	14	9.1	6.8	23	0.5	1.5
6	1.3	0.6	15	7.7	7.1	24	4.5	2.3
7	2.6	0.6	16	5.5	9.0	25	5.0	0.7
8	2.3	5.1	17	8.3	8.5	Average	4.5	3.2
9	2.1	7.2	18	9.1	7.1			

Theoretical approach

- Ray tracing simulations



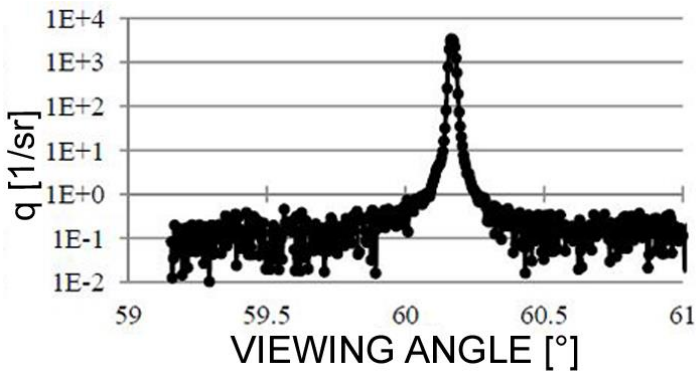
Ray tracing simulations

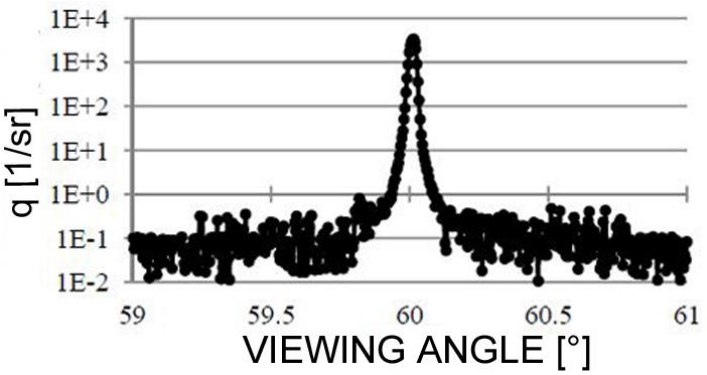
- Influence of tolerances on source/receptor apertures
- Influence of non-ideal angular conditions

	In plane of measurement		Perpendicular to plane of measurement	
	θ (°)	Relative dimension	θ (°)	Relative dimension
Source image	0.75	0.171	2.5	0.568
Tolerance	± 0.25	0.057	± 0.5	0.114
60° receptor	4.4	1.000	11.7	2.668
Tolerance	± 0.1	0.023	± 0.2	0.046

Surface charatceristics…

- BRDF data of 2 samples
  - Mid-gloss (27 GU)
  - High gloss (91 GU)





Simulation results

- Nominal apertures
  - 27 GU vs. 25.8 GU
  - 93 GU vs. 91 GU

- Aperture tolerances

		Sample 9 (low/mid-gloss)			Sample 19 (high-gloss)		
		Receptor aperture					
		Minimum	Nominal	Maximum	Minimum	Nominal	Maximum
Source aperture	Minimum	25.7	26.2	26.7	91.0	91.0	91.0
	Nominal	25.3	25.8	26.3	91.0	91.0	91.0
	Maximum	24.8	25.3	25.8	91.0	91.0	91.0

Simulation results

- Non-ideal angular conditions

		Sample 9 (low/mid-gloss)			Sample 19 (high-gloss)		
		Receptor aperture					
		Minimum	Nominal	Maximum	Minimum	Nominal	Maximum
Source aperture	Minimum	25.6	26.1	26.6	90.7	90.7	90.7
	Nominal	25.2	25.8	26.3	90.7	90.7	90.7
	Maximum	24.8	25.3	25.8	90.7	90.7	90.7

Conclusions

- Repeatability, checked in the recommended measurement geometry, is generally inferior to the specified recommendations.

- Reproducibility between each two instruments, again checked in the recommended measurement geometry, strongly depends on which two instruments are being compared.

- Correcting the results based on the linear correlation results in a better reproducibility, although threshold might still not be reached.

Conclusions

- Aperture dimensions + non-ideal angular conditions
  - deviations of 2GU for mid-gloss samples
  - In line with previous studies
    - +/- 1GU
    - Aperture dimensions more important that angular offset

- Further simulations?

- Adaptation of ASTM / ISO standards?
  - Repeatability/reproducibility as a function of gloss value/geometry?
  - Threshold limits as a function of gloss value?

Questions

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